

Impact of EGM2008 Geoid on Lake Surface Orthometric Heights Observed by SWOT and ICESat-2 Altimetry

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Background

- Gravitational Equipotential vs. **what we observe**: Lake surfaces are **equipotential**, but true orthometric heights vary due to **Earth's rotation and subsurface density**.

$$\Delta H_{PQ} \approx \frac{g_P - g_Q}{g_Q} H_P$$

- Sneeuw et al. at X Hotine-Marussi showed **theoretical variation** of approximately **6 cm** across the surface of Lake Michigan.
- Primary Target Lakes: **Large, deep, high-elevation, north-south** extending basins (where height variations are most pronounced).

Aim of the study - Relevant questions

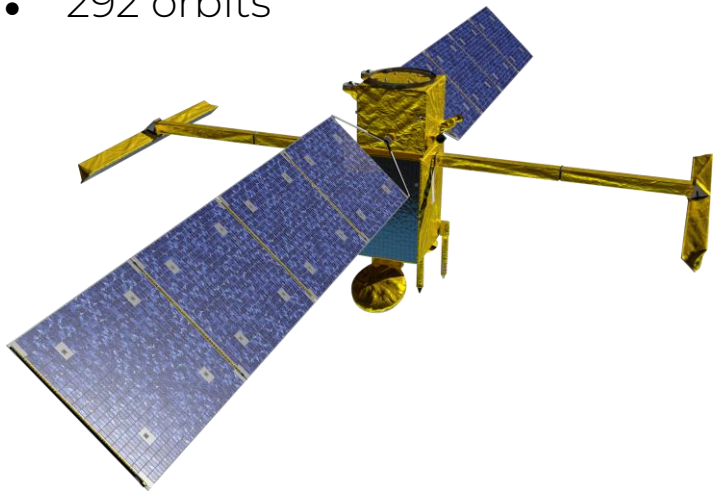
- Question: Are the observed lake-wide orthometric height gradients real, or are they **artifacts of the reference geoid**?
 - EGM2008 is the **prominently used height reference** in satellite altimetry studies.
- Question: **How much** the impact of **EGM2008** on lake orthometric heights acquired by altimetry?
 - **Investigate SWOT** observations using independent ICESat-2 measurements.

Data and study area

SWOT L2_HR_Raster

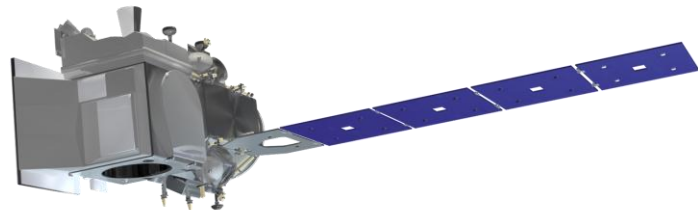
Ka-band Radar Interferometer (KaRIn) water surface elevations

- Coverage: 78°S–78°N
- Repeat cycle: **21 days**
- 292 orbits



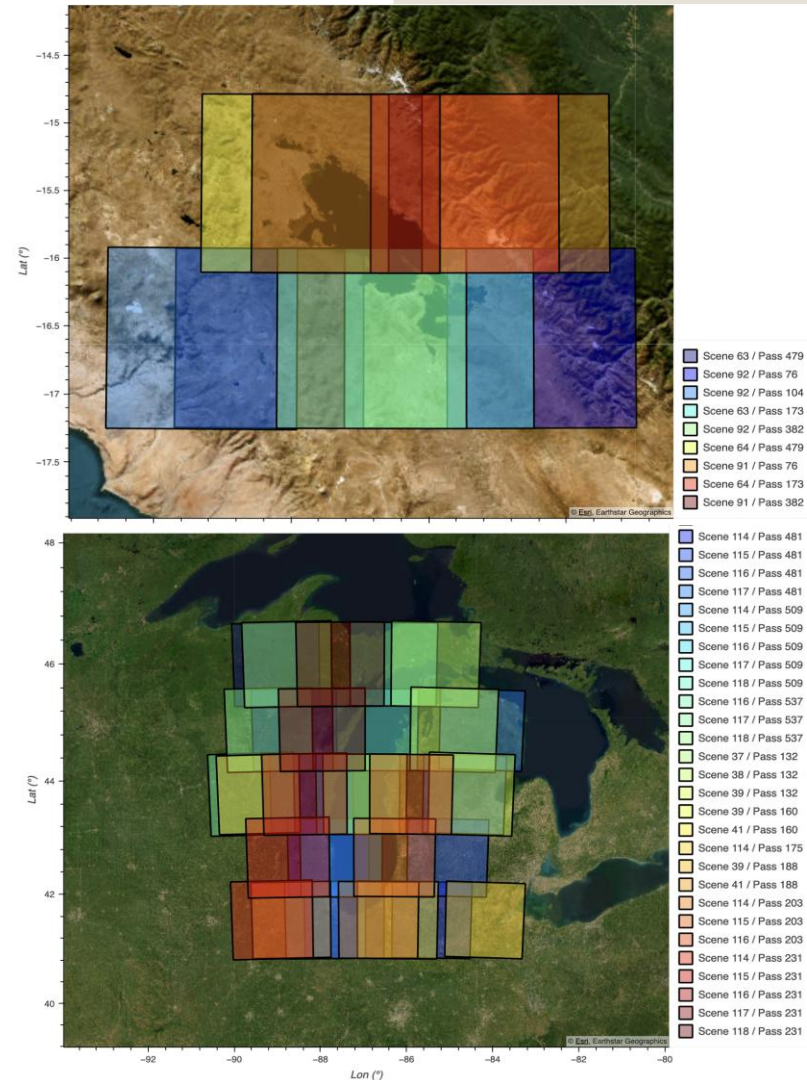
ICESat-2 ATL13

- Few-centimeter accuracy
- High precision measurements
- Near-polar orbit: 92° inclination
- Revisit time: **91 days**
- Independent validation of SWOT observations



Data and study area

- SWOT and ICESat-2 measurements are referenced to **EGM2008**.
- Corrected for atmospheric and tidal effects.
- Epochs of ICESat-2 with close proximity to SWOT acquisition.
- Lake **Titicaca** with altitude of 3,800m and Lake **Michigan** at 180 m.
- 28 SWOT scenes cover the entire Lake Michigan and 9 cover the Lake Titicaca.
- **Bouguer gravity anomaly** acquired from BGI.



Method

- Acquiring ICESat-2 (product: **ATL13**) over SWOT (product: **L2_HR_Raster_100m_2.0**) activity period (after Cal/Val phase and from Sept 2023 onwards).
- Acquisition of **SWOT closest scenes prior and after ICESat-2** acquisition dates.
- Computation of a **median** based mosaic of SWOT scenes.
- **Water masking** using **Global Surface Water** of JRC Data Catalogue (GSW).

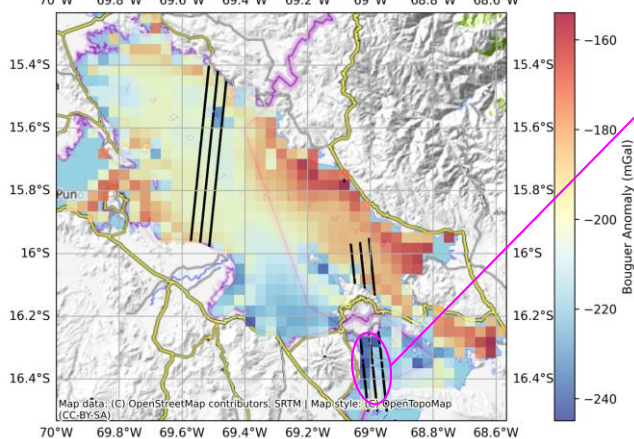
Method

- Outlier removal using the internal flags for both SWOT and ICESat-2.
 - SWOT with **wse_qual == 0** — WSE being Water Surface Elevation
 - ICESat-2 with **qf_sseg_length == 9** and **qf_cloud == 0**
- Sampling SWOT using ICESat-2 geolocated points over a single orbit.
- Transforming Lake Michigan WSE to **GEOID2022** orthometric height.

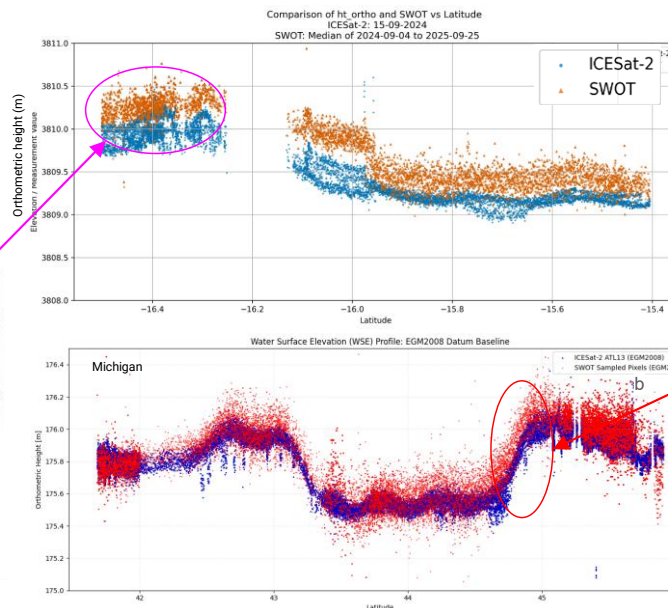
Results

- Is there a relationship between **Bouguer anomaly** and the water surface height?
- 65% correlation

Geolocation Points on Lake Titicaca with ATL13 and Bouguer Anomaly



a

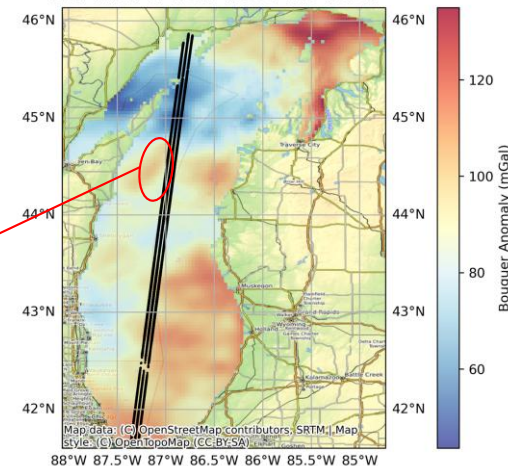


SWOT_START = "2024-02-08"

SWOT_END = "2024-03-03"

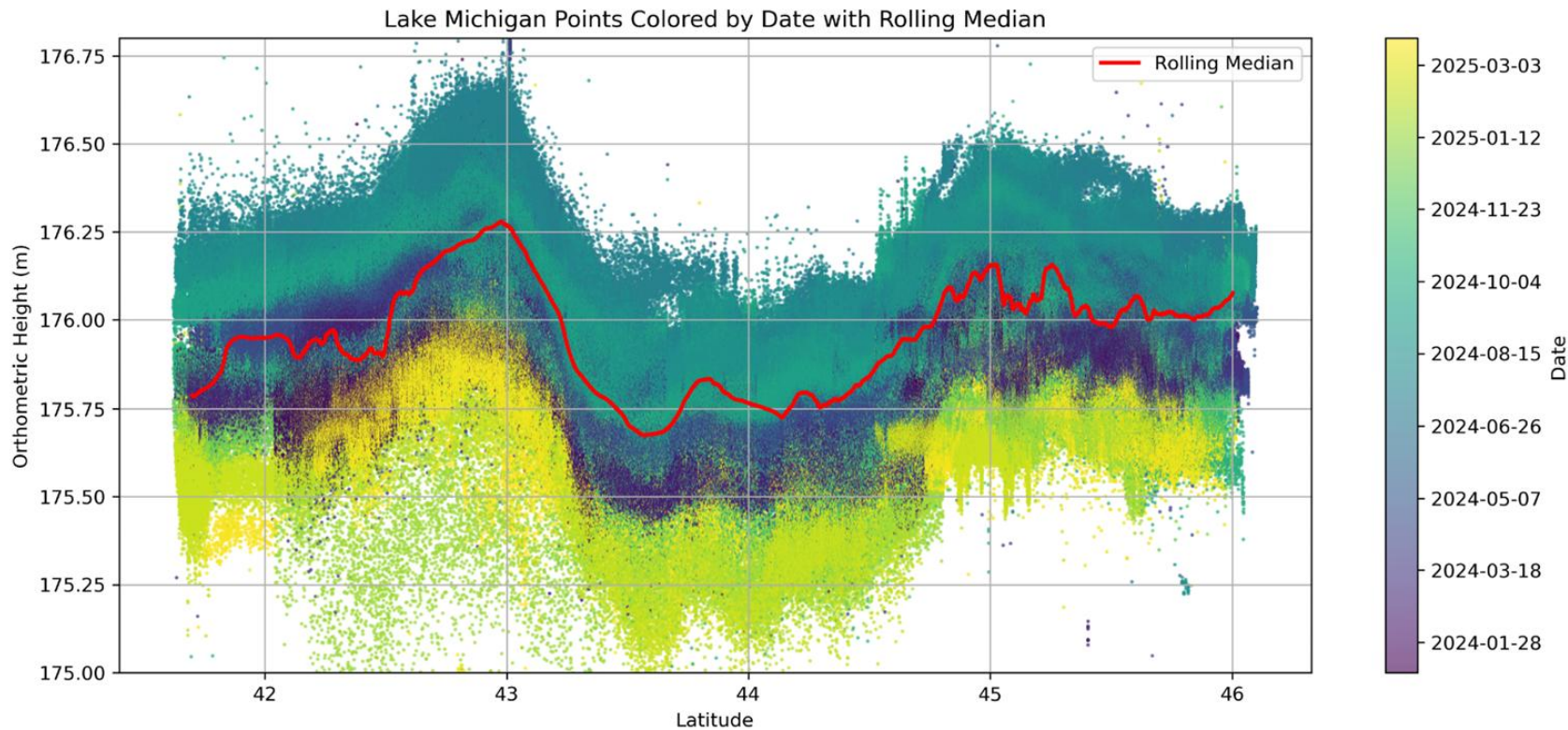
ATL13 = "2024-02-19"

Geolocation Points on Lake Michigan with ATL13 and Bouguer Anomaly

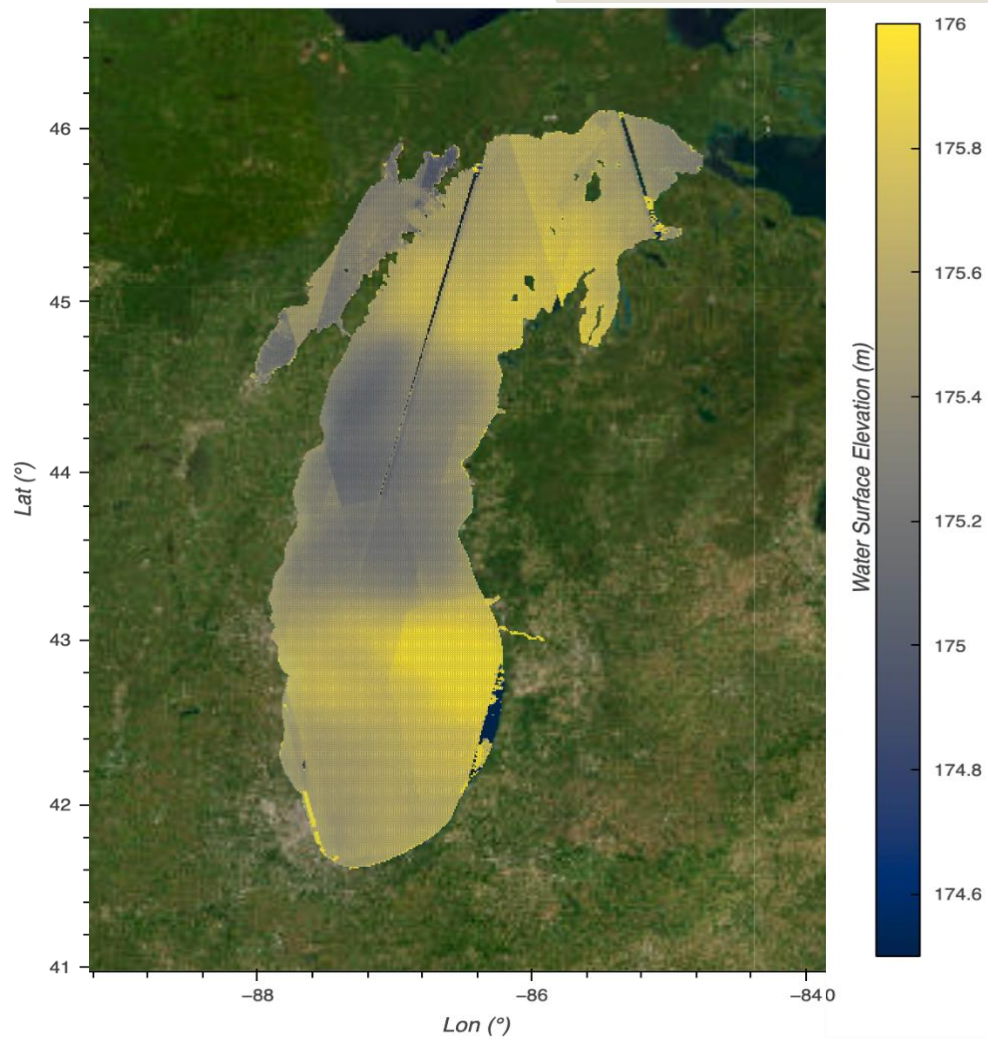
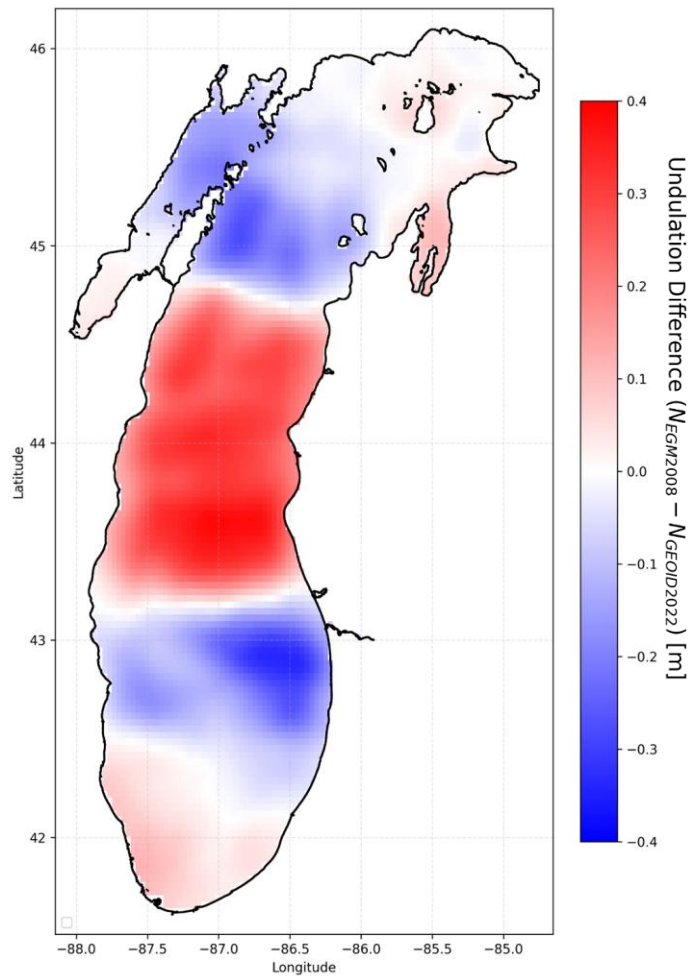


d

Results

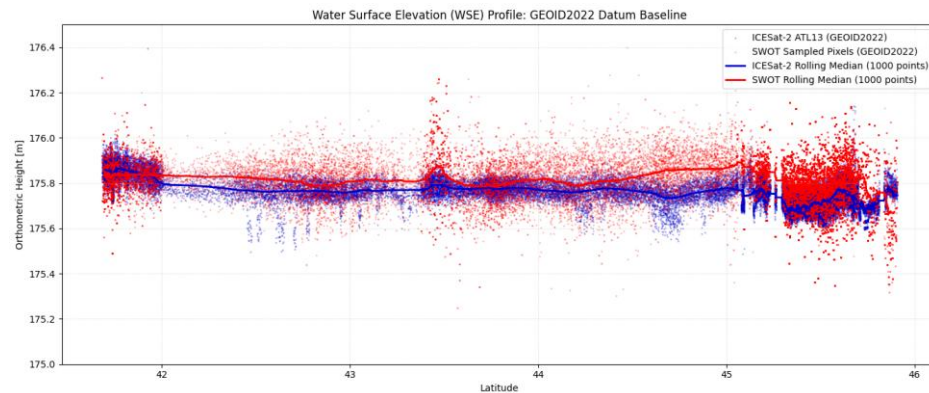
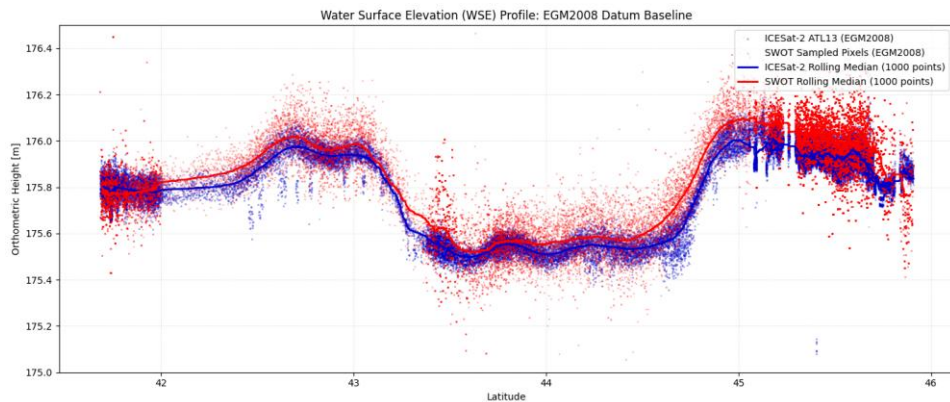


Difference EGM2008 and GEOID2022



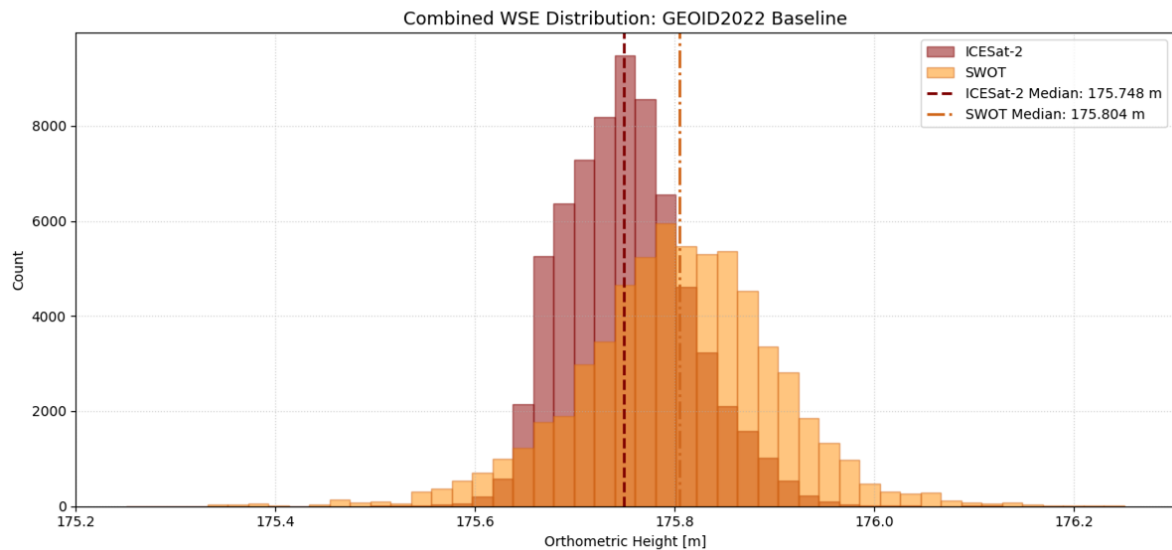
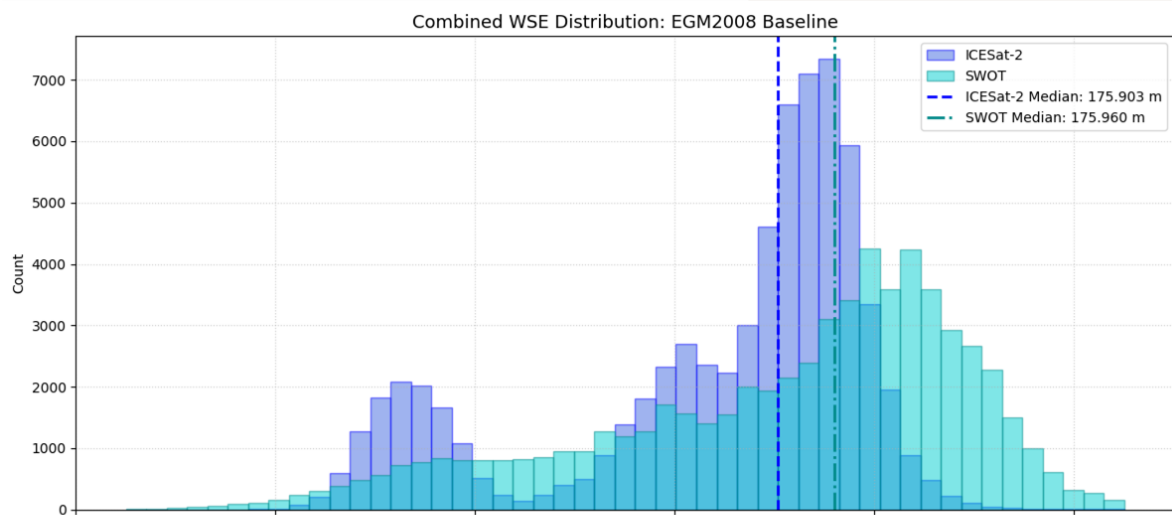
Results - Lake Michigan

stats	ICESat-2 (EGM2008)	SWOT (EGM2008)	ICESat-2 (GEOID2022)	SWOT (GEOID2022)	Difference
Mean Height (m)	175.85	175.91	175.75	175.80	-0.06
Median (m)	175.91	175.96	175.74	175.80	-0.06
P25 (m)	175.80	175.80	175.70	175.74	-0.13
P75 (m)	175.96	176.05	175.78	175.87	0.01
SD (m)	0.16	0.19	0.06	0.10	0.11
NMAD (m)	0.09	0.16	0.06	0.09	0.10



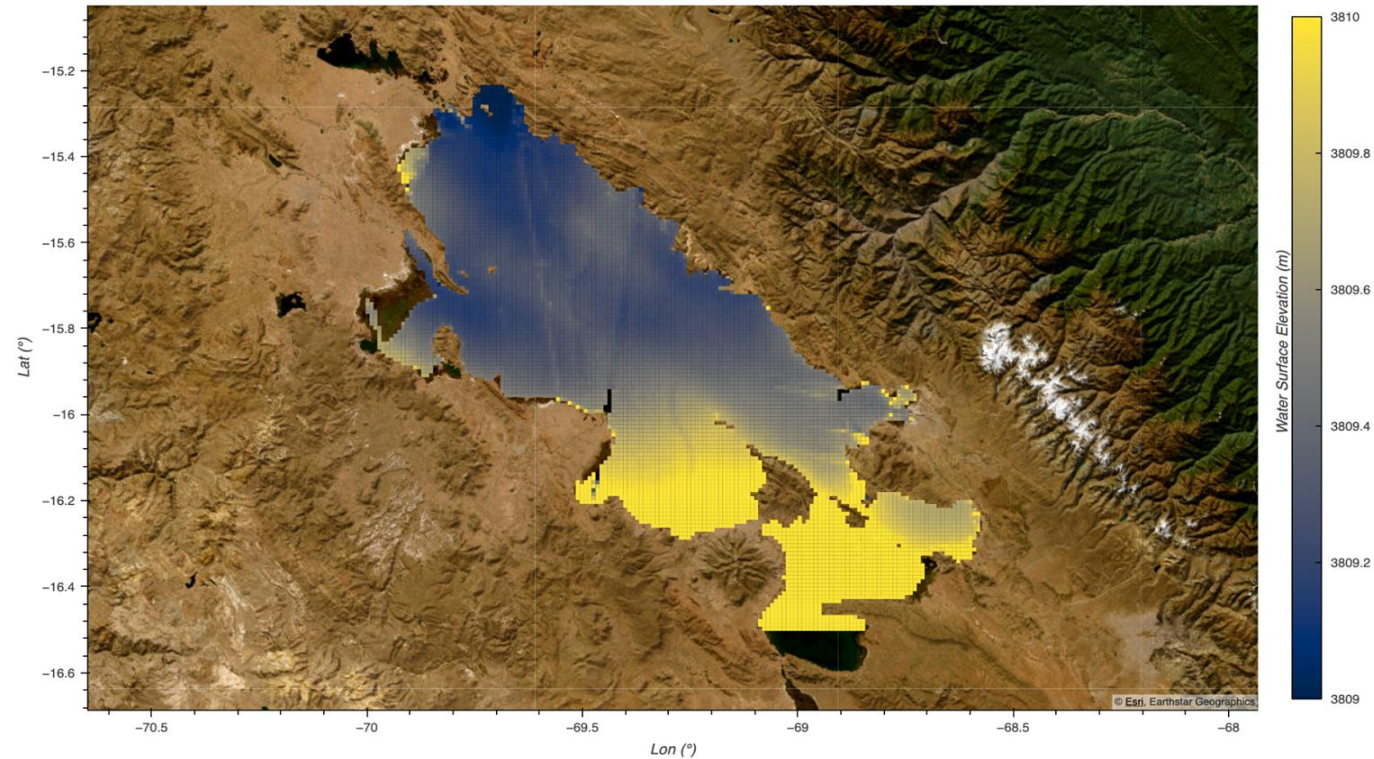
Results

- **Bimodal** to **unimodal** due to the **shape of the undulation**
- **Narrower** and **less skewed** and more precise
- There is the effect of **longer time span of SWOT** acquisition



Results

- In Lake Michigan the **beginning and end values** was the Lakes elevation
- Titicaca has **anomalies all over the lake**



Conclusions and future work

- Move on from EGM2008 to XGM2019.
- Increase precision in case of sparse data sets (e.g. GEDI) where a lot of data is noise.
- Could we go the opposite way? Improve the the geoid with these water level variation?
- We need to better include the new altimetries over the lakes in the course of new geoid estimations.
- Extend the analysis for further confirmation (e.g. Huron, Baikal).

Thank you for your attention

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Results

